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Yellow-cedar Stecklings: Nursery Production and Field Performance

by

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1 INTRODUCTION

Six-year-old yellow-cedar trees of steckling origin.

Stecklings, or plantable rooted cuttings, are the primary propagule type used for artificial regeneration of yellow-cedar (*Chamaecyparis nootkatensis* (D.Don) Spach.) in British Columbia. An increase in logging of this valuable species has resulted in a greater demand for planting stock which cannot be met by seedling production. This is due to infrequent cone crops, and seed which usually has poor germination success. From 1975 to 1986, over 50% of all yellow-cedar stock planted in British Columbia have been stecklings. Since 1987, an average of 650 000 stecklings have been planted on reforestation sites annually, accounting for over 90% of the planting stock.

The use of an alternative propagule for reforestation raises many questions. How do stecklings compare to seedlings with respect to nursery production, stock quality, and physiological tolerance to environmental stress which affects survival and growth in the field? What are the advantages or disadvantages of using stecklings over seedlings, or of using stecklings originating from different maturation levels? How important is the influence of donor stock physiology, genetics, and maturation with respect to rooting, nursery stock quality, and field performance?

Large-scale production techniques of yellow-cedar stecklings were developed mostly at Cowichan Lake Research Station in the late 1970's and early 1980's (Karlsson 1981). Operational production was transferred to commercial nurseries in the mid-1980's. Many questions were still unanswered, however, about the rooting of yellow-cedar and subsequent performance in the nursery and field. Steckling research over the last 5 years with yellow-cedar has concentrated on the physiological and genetic basis for rooting and the subsequent steckling performance; and on improving nursery production efficiency through manipulation of cultural practices.

This report synthesizes the research results and operational experiences from the last 15 years concerning nursery production and field performance of yellow-cedar stecklings.

2 NURSERY PRODUCTION

Yellow-cedar cuttings can root very easily. Cuttings taken from healthy 1-year-old seedlings will root with almost 100% success and produce plantable rooted cuttings comparable to seedlings in one growing season. However, when the process is expanded to produce hundreds of thousands of stecklings economically, potential problems can develop.

The success of an operational rooted cutting program depends upon good management of donor stock and proven nursery techniques.

2.1 Cutting Donor Management

In a large-scale rooted cutting program such as the one for yellow-cedar, a major problem is obtaining good quality cutting material. With a limited amount of seed, it is not possible to produce enough cutting material from 1-year-old seedlings to meet the demand for stecklings. Thus, methods must be developed to "bulk-up" the amount of cutting material. One method would be to collect cuttings from older trees, but unfortunately these cuttings do not root very well and the subsequent stecklings exhibit poor growth and form. The reason for this is a combination of the effects of cutting donor maturation, physiology, and genetics.

Fortunately, techniques are available to obtain a large number of quality cuttings from a single donor on a continuous basis, by manipulating the maturation level, physiology, and genetic source of the cutting donor. The following section examines factors that influence the production of quality cutting material and the techniques that have been developed for producing cutting material.

2.1.1 Cutting donor maturation level

Conifer tissue matures because of: 1) chronological aging (e.g., 1-year-old seedling versus 10-year-old tree); 2) ontogenetical aging, which is the irreversible change in genetic expression (e.g., change from juvenile leaf forms to mature leaf forms); and 3) physiological aging, (e.g., changes in hormonal composition and levels). Maturation of cutting donors can be manipulated by selecting the crown position from which cuttings are taken; annually pruning the cutting donor; or repeatedly taking cuttings from recently rooted cuttings ("serial propagation").

The maturation level of the cutting donor influences rooting success and subsequent steckling performance in several ways (Figures 1, 2, and 3):

- **As the cutting donor ages, rooting success, rooting speed, and stock quality declines.** Generally, cuttings taken from healthy non-hedged trees up to 3 years of age will have high rooting success, good stock quality, and low cull rates.
- **Cuttings taken from the lower unshaded crown of a tree will have greater rooting success, rooting speed, and overall stock quality.** This difference first becomes apparent with 3-year-old trees, and becomes more pronounced as a tree ages.
- **Hedging of a donor tree delays maturation, and thereby improves rooting success, speed of rooting, and stock quality. A closer hedging to the ground improves the response.** Hedging benefits donors as young as 3 years of age by concentrating cutting material in the lower portion of the crown.
- **Serial propagation results in improved rooting success, rooting speed, and stock quality.** Serial propagation is a powerful technique for not only improving cutting quality, but also rapidly increasing cutting material availability.

Recently rooted yellow-cedar cuttings.

Horizontal shoot growth (plagiotropism) of a 2-year-old yellow-cedar steckling which originated from the top of an 11-year-old tree.

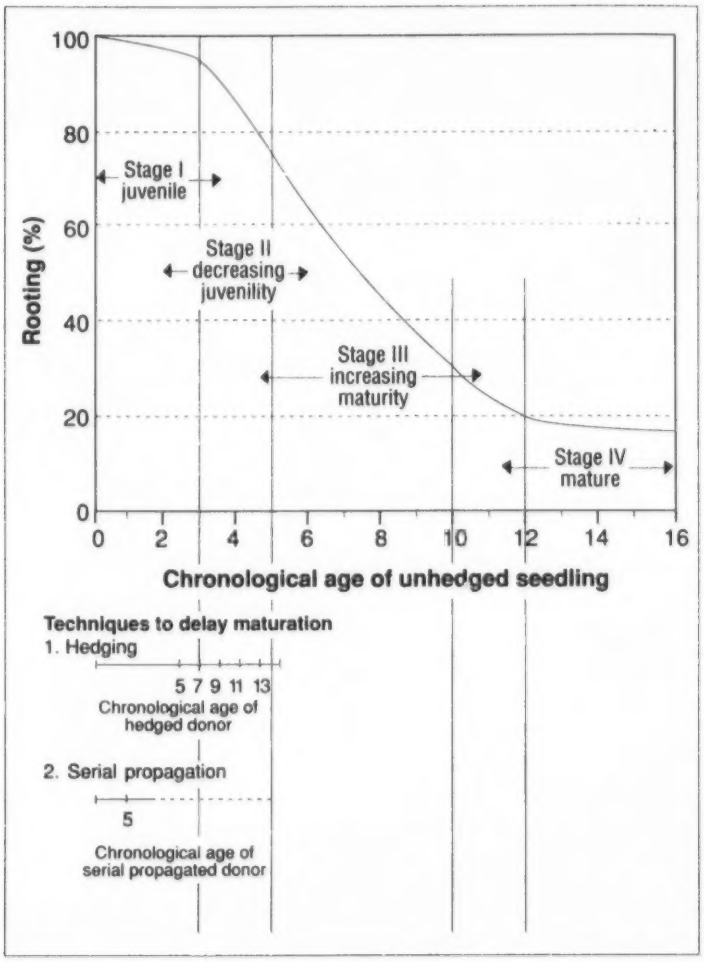

FIGURE 1. Stages of maturity of yellow-cedar as determined by rooting success.

This figure, compiled from the results of many research and operational rooting trials, illustrates the relation between rooting success and cutting donor maturity. (A cutting is considered to be successfully rooted only if it has formed a firm root plug.) Rooting success declines with increasing chronological age of the seedling cutting donor such that four overlapping and arbitrary stages of increasing maturation can be delineated:

I. juvenile (greater than 85% rooting)
II. decreasing juvenility (greater than 75% rooting)
III. increasing maturity (less than 75% rooting)
IV. mature (less than 40% rooting)[1]

A similar curve could be drawn using rooting traits such as number of main roots or symmetry of main roots; or steckling traits such as stem straightness or root collar diameter.

Techniques have been developed to delay maturation and improve rooting success and stock quality. For example, cuttings from hedged 5-year-old seedlings have similar rooting success to that of cuttings taken from 3-year-old seedlings. As well, cuttings from hedged 13-year-old seedlings behave similarly to cuttings from unhedged 5-year-old seedlings. This technique can result in a cutting donor moving from Stage IV to Stage II.

Serial propagation is very successful in delaying maturation. Cutting donors that have gone through three cutting cycles (1 year between cycles), starting with a 2-year-old seedling (i.e., 5 years from seed), produce cuttings which root with 100% success.

[1] Cutting donors from Stages I and II are considered acceptable for producing cutting material. Cuttings from donors in these two stages of maturation root with greater than 75% success, and the resultant stecklings are comparable to seedlings in growth and form traits.

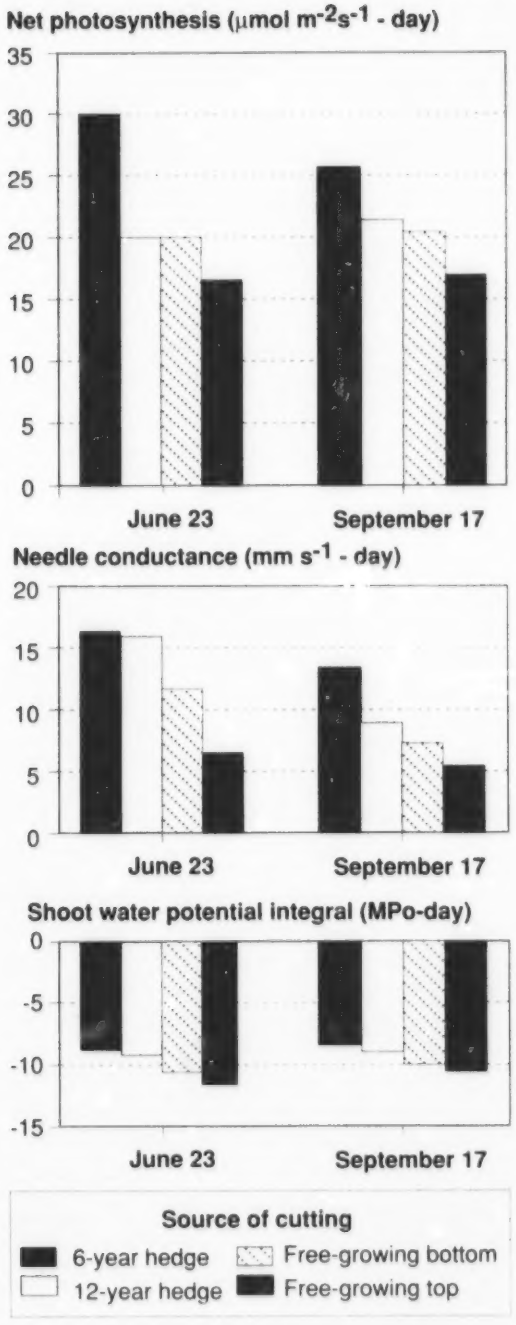

FIGURE 2. The effect of age and pruning on cutting donor physiological vigour: 1) net photosynthesis; 2) needle conductance; and 3) shoot water potential.

Production of high quality cutting material must begin with the proper maintenance of cutting donors. Development of desirable cutting donors should be based on cultural practices which influence donor traits that enhance cutting quality. Knowledge of the physiological patterns of the cutting donor will give growers a partial understanding of donor stock influence on cutting quality.

Research has shown hedged stock to have higher physiological vigour (i.e., greater daily net photosynthesis and stomatal conductance) and lower water stress than free-growing trees of the same age. Physiological vigour also increased with younger hedged cutting donors. These results indicate that hedged cutting donors have the potential to be superior to free-growing trees as donor material.

Nursery Cultural Implications

Cutting material should come from donors that are in maturation Stages I and II as defined in Figure 1. Cutting donors should be pruned annually after the first growing season to produce a large number of cuttings and to delay maturation. Research has shown cutting donors can be pruned for up to 13 years and still produce stecklings of comparable quality to seedlings.

Another technique for delaying maturation while bulking-up cutting material is serial propagation. This method can be used in one of two ways. The first involves the bulking-up of a limited supply of hedged cutting donors through serial propagation. Over 1 million cuttings could be produced from 100 seedlings in just 4 years using a combination of accelerated growth, serial propagation, and hedging of cutting donors. This would not be advisable, however, because of the potential loss of genetic diversity.

The second use of serial propagation involves collecting cuttings from 1-year-old seedlings or 1-year-old stecklings originating from juvenile material (Stage I) These cuttings are then used to produce the next year's stecklings. Details of this technique are described in Section 3.

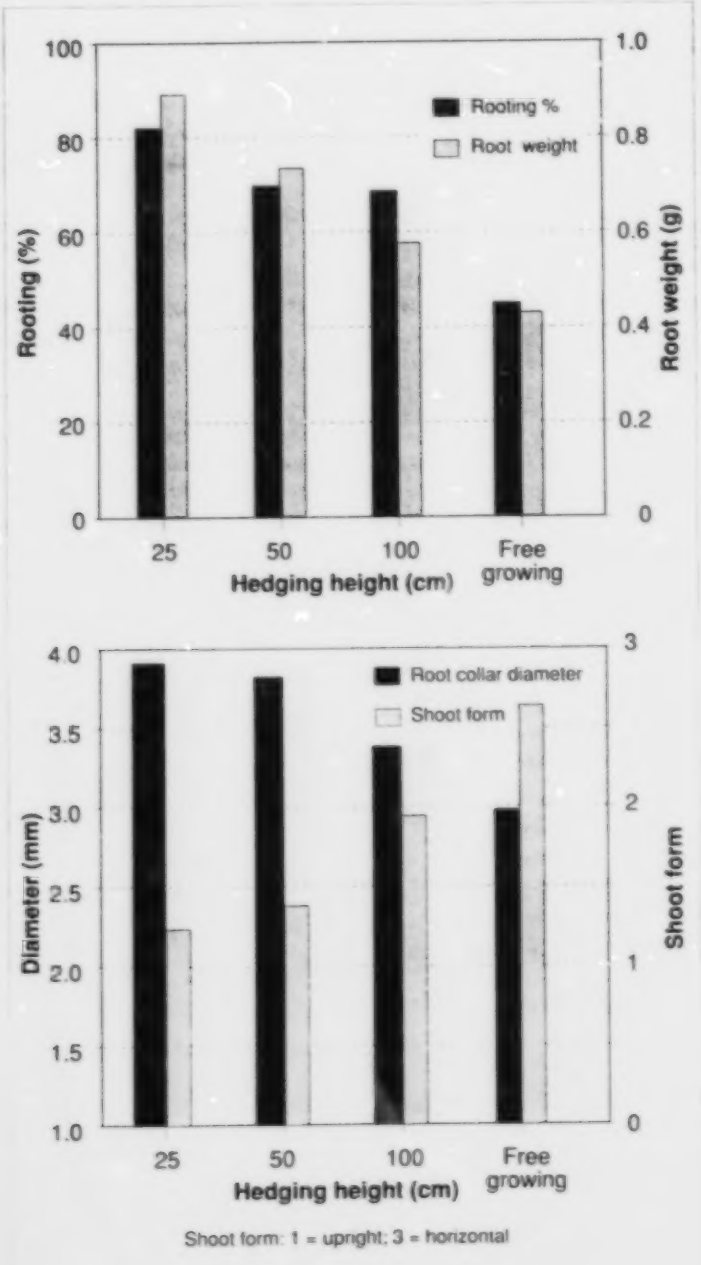

FIGURE 3. Effect of hedging height in 10-year-old trees of seedling origin on the performance of 1-year-old yellow-cedar stecklings: 1) rooting success and root dry weight; and 2) root collar diameter and shoot form.

Annual pruning of cutting donors will improve the cutting material quality, and closer pruning to the ground results in a better response. Cuttings from hedges pruned to 25 cm have resulted in improved rooting success, greater root mass production, increased number of main roots, better main root symmetry, increased root collar diameter, and straighter stems. By annually pruning the cutting donors, nursery cull rates will decrease, and stock quality will be improved.

2.1.2 Physiology of the cutting donor

Cutting donor physiology can influence rooting success and stock quality in a number of ways:

- **Rooting success is improved if cuttings are taken before the first frost or after 200-300 hours of chilling at or below 3 °C (Figure 4).**
- **Application of exogenous hormones to cuttings for improving rooting success becomes more important as the cutting donor matures.**
- **Cutting from donors that are well watered, properly fertilized, and not shaded improves rooting success.**

2.1.3 Genetics of the cutting donor

Cutting donor genetic source can influence rooting success and nursery stock quality in several ways:

- **Rooting success differs between families and between clones of more mature cutting donors.** This difference does not become apparent until the cutting donors are in Stage II of maturity (Figure 5).
- **Cutting donor families respond differently to hedging.** Genetic differences in maturation response to hedging results in different cutting responses to rooting success and stock quality.
- **Cutting donor genetic source influences nursery stock quality.** First-year height, root collar diameter, root form, and root dry weight can all be improved if selections are made among families and clones of cutting donors. There is a positive correlation between rooting success and nursery stock quality.

Nursery Cultural Implications

Cutting donors should be adequately watered and fertilized with a balanced fertilizer throughout the growing season. Cuttings from shaded foliage on the bottom of the hedged donor should not be used. Cutting donors grown in containers in the nursery should be well spaced to increase the proportion of useable material from each donor. Cuttings should be collected before any chilling or after 300-400 chilling hours, not according to calendar dates. They should also be collected when in a turgid condition. If the cuttings are from more mature material (Stages II and later), an exogenous hormone should be applied (see Section 2.2 for more information).

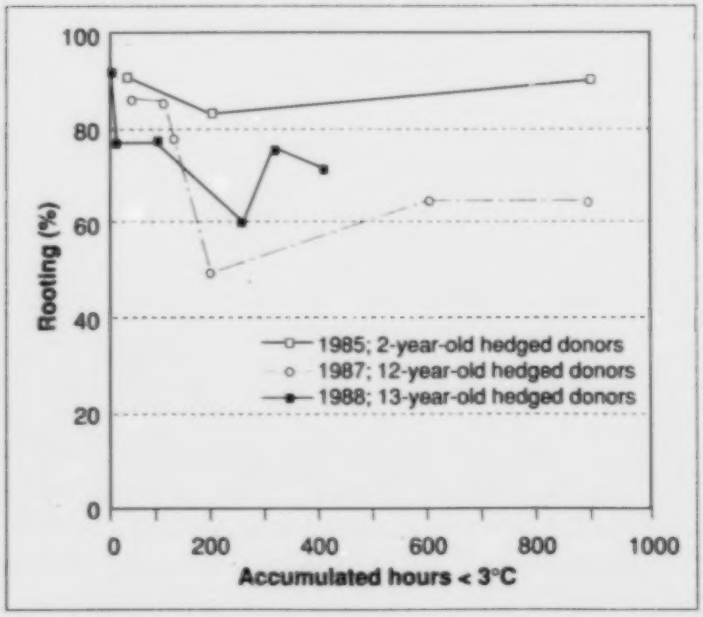

FIGURE 4. The effect on rooting success of time of year in taking and setting yellow-cedar cuttings.

In a series of annual time-of-year rooting trials, the decrease in rooting occurred at or around the first cold weather, and continued to decrease until approximately 200-300 hours of chilling at or below 3 °C had accumulated. Rooting success increased after the accumulation of the required chilling hours, however it was usually best when the cuttings were taken before the cutting donors experienced any substantial cold weather. The decline in rooting success during the chilling period is more pronounced for cuttings from Stage II donors.

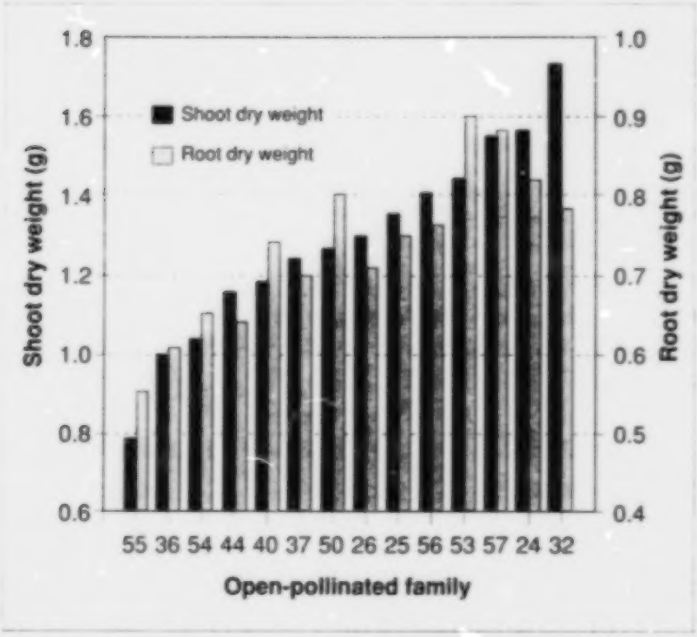

FIGURE 5. The effect of genetic source of cutting donor on shoot and root dry weights of 1-year-old stecklings.

The genetics of the cutting donor plays a major role in determining the success of the subsequent rooted cutting. After all, when a cutting is taken from a donor, it contains all of the genes of the donor. Of the 28 open-pollinated families represented in the CLRS hedge orchard, rooting success ranged from 48 to 95% for cuttings taken from 12-year-old donors, based on family means. Family means for 1-year-old rooted cuttings grown in Capilano containers (plastic 313's) ranged from 17 to 27 cm for height, 2.7 to 3.8 mm for root collar diameter, 0.45 to 0.70 for root:shoot ratio, and 4.9 to 7.6 for number of main roots.

Nursery Cultural Implications

To improve rooting success, stock quality, and subsequent field performance through genetic manipulation, family and clonal hedges (i.e., rows of hedges kept separate by genetic identity) should be established. These hedges can then be culled by family or clone, according to either rooting success, first-year nursery stock quality, or growth in the field. This will increase overall rooting success, decrease cull rates, and improve initial field establishment and growth.

2.2 Nursery Cultural Practices

Many factors other than the condition of the cutting donor contribute to the successful propagation of yellow-cedar cuttings. There is usually a maturation response to cultural treatments among the cuttings from Stages I and II donors. This is attributed mainly to speed of rooting (see Figure 6). It is therefore important that a grower know the cutting maturity levels so that they can be kept in separate greenhouse locations. This will allow nursery cultural treatments to be applied by maturation level during the rooting and growing phases.

The following nursery cultural practices can influence rooting success and steckling quality:

- **The size of cutting (ranging from 3 to 10 cm) does not affect rooting success, but it does affect the ability of the rooted cutting to reach target specifications for 1-year-old propagules.** Insufficient root mass from 3-4 cm cuttings results in less shippable cuttings. Cutting size, especially for mature cuttings, should be greater than 6 cm.

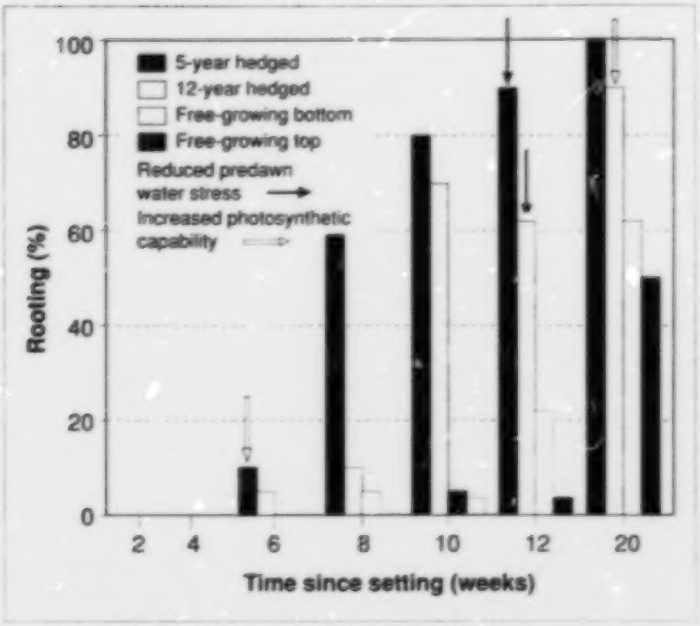

FIGURE 6. The effect of cutting donor maturation on rooting physiology.

Cuttings must be maintained in a non-stressful nursery environment to ensure success of the rooting process. However, growers need to know the optimal time to transfer the cuttings to a seedling environment, to encourage shoot growth as well as root growth. Research has shown that the rate at which rooting occurs, the physiological responses of the cuttings to their environmental conditions, and rooting success are all related to cutting donor age and maturity. Cuttings from 5- and 12-year-old hedged donors required 12 and 20 weeks, respectively, in the rooting environment before being ready for transfer to a seedling environment. Cuttings from older free-growing trees require longer periods of times in the rooting environment. The more juvenile the cutting donors, the less physiological stress the cuttings experience, and the more quickly they root and begin to function similar to seedlings.

- **Cuttings that are sufficiently hardened can be stored at 4°C up to 1 week without any detrimental effects on rooting and up to 8 weeks with minimal decrease in rooting.**
- **Rooting success of cuttings from Stage II donors is increased by an application of rooting hormone.**
- **Cutting maturation level dictates container type and cavity size, growing media, and watering regime during the rooting phase.** Compared to cuttings from Stage I, (Figure 6) cuttings from Stage II and later stages take longer before they start to root, and they therefore have less time available to grow roots.
- **Timing for initiating a cutting fertilization regime affects rooting success and stock quality and is influenced by cutting donor maturation (Figure 7).**

Nursery Cultural Implications

In a large-scale rooting program such as that for yellow-cedar, there will always be a wide variety of cutting material available. Thus, a grower will be faced with cuttings from a mixture of donor sources and maturity. Cutting history and donor plant source are essential information for a successful propagation program.

To maximize the number of cuttings from the best material, smaller cuttings (6-8 cm) should be taken. These should be kept separate from larger cuttings because of the different water demands early in the rooting process.

The rooting response of Stage II cuttings to different hormonal treatments varies widely and depends on many factors. The most consistent results have been obtained by the quick-dipping of cuttings in a commercial rooting hormone containing a mixture of 0.8% I.B.A. and talc. Encouraging results have also been obtained by the addition of 50% Benomyl to the I.B.A. and talc mixture. Rooting success of cuttings from Stage I donors do not usually benefit from an application of rooting hormone.

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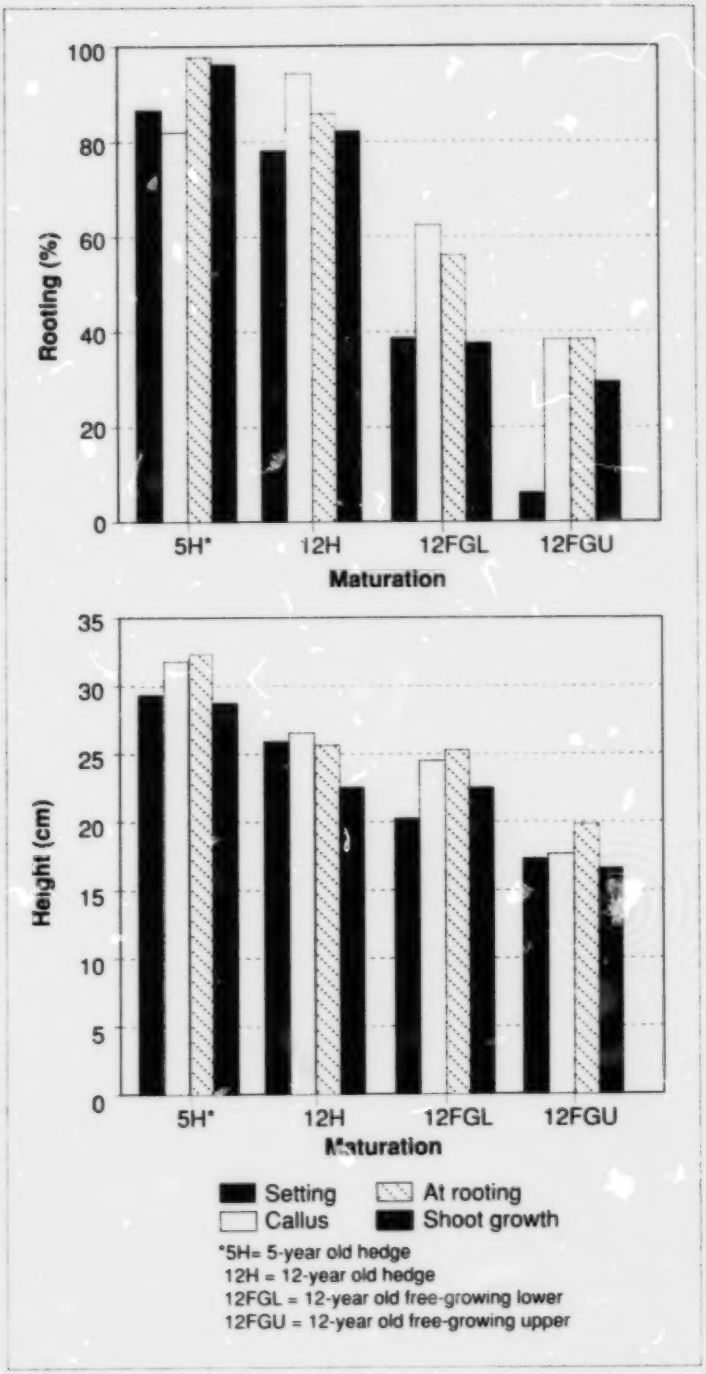

FIGURE 7. The effect of maturation level of cutting donors and the effect of timing for initiating a soluble fertilizer regime: 1) rooting success; 2) first-year height.

Since there is a difference in the rooting speed of cuttings taken from different maturation levels, fertilization and watering programs should be adjusted accordingly. The best time, in terms of rooting success and steckling quality, to initiate a soluble fertilization regime is the point at which cuttings have callused and are just starting to root.

If a soluble fertilizer regime is started at the time of setting for juvenile cuttings, there is no decrease in rooting. For mature cutting material, however, fertilized at setting, there is a decrease in rooting. Early fertilization of juvenile cutting material results in no improvement of height growth, root collar diameter, root form, or root and shoot dry weights.

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Since cuttings from Stage II donors take longer to root, they should be: 1) kept separate in the greenhouse and watered less frequently during the rooting phase; 2) set in containers with smaller cavity size (styro 313); 3) set in a growing media higher in perlite than peat; 4) set earlier than Stage I cuttings; or 5) set according to a combination of the above.

Cuttings from Stage I donors produce so much root mass that a high cull rate from root tearing is inevitable if these cuttings are set in small cavities (styro 313) which have been used for a number of years. Stage I cuttings should be set in either plastic containers, new styro containers, or larger cavity sizes (>17.8 cm³).

A soluble fertilization regime should not begin until cuttings — especially those from Stage II donors — start to root. As well, Stage II cuttings should not be stuck in growing media containing a slow release fertilizer.

To maximize the number of shippable plants, different size cuttings and cuttings from different maturation stages should be kept separate in the greenhouse so that the proper cultural treatments can be applied at the appropriate time.

2.3 Operational Production

Yellow-cedar cutting donor and steckling production has been going on at Cowichan Lake Research Station (CLRS) for 15 years. This program first started out as a small rooting trial to attempt to bulk-up provenances for an arboretum (I. Karlsson, pers comm.). It then expanded to the annual operational production of 300 000 cuttings taken from a 2-ha hedge orchard. The operational production of stecklings has now been transferred to commercial nurseries. Approximately 50 000-100 000 stecklings are still produced annually at CLRS, using various techniques for producing cutting donors and various nursery regimes for rooting and growing cuttings.

2.3.1 Cutting donors

Three sources of cutting material are used: a soil-based hedged orchard; a container hedge orchard; and 1+0 seedlings and juvenile stecklings (at Stage I maturation level).

Soil-based hedge orchard

The hedge orchard at CLRS was planted with 1+1 seedlings from selected open-pollinated families and seedlots in 1978 and 1979. There are approximately 2000 seedlings planted at 3.75 m between rows, and 1 m within rows. New rows are currently being planted using open-pollinated families and seedlots, with a 1.8-m spacing between rows.

Older donors have been pruned annually since 1982 and younger plants after the first year of planting. The cutting donors are pruned to below 30 cm in a bowl shape. The best cutting material will occur in the middle of the bowl closest to the ground and where no shading occurs. Pruning is done in late winter after cutting material has been taken.

Trickle irrigation provides moisture during periods of drought or for newly planted rows. Hedges are fertilized twice during the growing season with a 1:1 mix of 19-19-19 (2.8g N per tree and 34-0-0 (5.1g N per tree). Weeds are controlled with Simazine®, a pre-emergent herbicide, twice a year at 0.3 g/L; Vision® (glyphosate) at a 1% solution; and Amitrol® T (amitrole), at 10 L/450 L water to control horsetail.

Cuttings from the hedge orchard have actually increased in rooting ability over time. The cutting donors undergo a planting shock for a couple of years, which results in reduced rooting. However, as donors become established and start to respond to the annual pruning, rooting increases. Since 1987, overall rooting has been just under 80%, with approximately 60% shippable rooted cuttings being produced. However, if families that have consistently poorer rooting success are "rogued" out of the orchard, then overall rooting is improved to 88% and shippable rooted cuttings to 70%.

Yellow-cedar hedge orchard at CLRS.
At full production, the orchard could supply over one-half million cuttings annually (4000 cutting donors in 2 ha).

Container hedge orchard

To increase the production of good quality, easy-to-root juvenile cutting material (i.e., at Stage I), 1+0 seedlings are potted into 5-L containers and held in greenhouses or holding areas for intensive cultural management (Table 1).

Seedlings are grown in larger containers (styro 415) for the first year and grown to over target height (30-40 cm). At time of transplant into 5-L pots (winter) the seedlings are topped to 15 cm. Donors are placed into a greenhouse in early spring and supplemental heat (10-12 °C) is applied as needed. The donors are adequately spaced to promote good crown development, and pruned twice during the growing season. In following years, the donors are either left in the greenhouse or mulched into holding areas, again with adequate space left within and between rows.

Two-year-old hedges can produce 35-50 cuttings 6-8 cm in length. Hedged donors in the 5-L containers produce quality cuttings for up to 5 years.

TABLE 1. Growing media and fertilization regimes for the production of container hedge orchards

Event	Details
Year 1 (sowing)	
1. media	0.72 m^3 peat 0.12 m^3 perlite 0.12 m^3 vermiculite 2.5 kg dolomite lime 1.0 kg gypsum 1.0 kg Micromax® 2.0 kg Osmocote® 18-6-12
2. fertilizer	-high soluble 20-20-20 @ 0.5 g/L biweekly, plus Stem® @ 0.5% of fertilizer by weight -0-52-17 @ 0.5 g/L as finisher
Year 2 (5-L pots)	
1. media	0.6 m^3 hog fuel 0.12 m^3 peat 0.12 m^3 vermiculite 2 kg dolomite lime 1 kg gypsum 1 kg 0-25-0 1 kg Micromax® 5 kg Osmocote® 18-6-12
2. fertilizer	-high soluble 20-20-20 @ 0.5 g/L weekly, increase as required -$CaNO_3$ application once during growing season -reduce nitrogen to harden
Year 3+	
1. greenhouse	-treat same as Year 2 donors
2. outside	-top dressing of Osmocote® 14-14-14 once per year

Yellow-cedar 2-year-old container hedge orchard.
A 12.2 x 36.6 m greenhouse will hold 10 000 cutting donors, and potentially produce 250 000 6-8 cm cuttings annually for up to 5 years.

One-year-old production stock

Up to six cuttings can be taken from the tops of 1-year-old seedlings, or 1-year-old stecklings that originate from juvenile cutting donors (Stage I). The propagules are grown over the target height of 17-20 cm in the first year to provide the cutting material. At the time of lifting, the propagules are wrapped in bundles of 25 and the top 10-15 cm are cut off into plastic bags to be cold-stored until being set. A side branch of the pruned seedling or steckling will usually assume dominance after one or two growing seasons in the field.

Although this option is attractive, there have been reports that top-pruned yellow-cedar are set back in the field at least 2 years compared to unpruned stock. One technique to circumvent this potential problem is to take cuttings from the actively growing plants in the summer, thus allowing time for the seedlings or rooted cuttings to reassert dominance in the nursery.

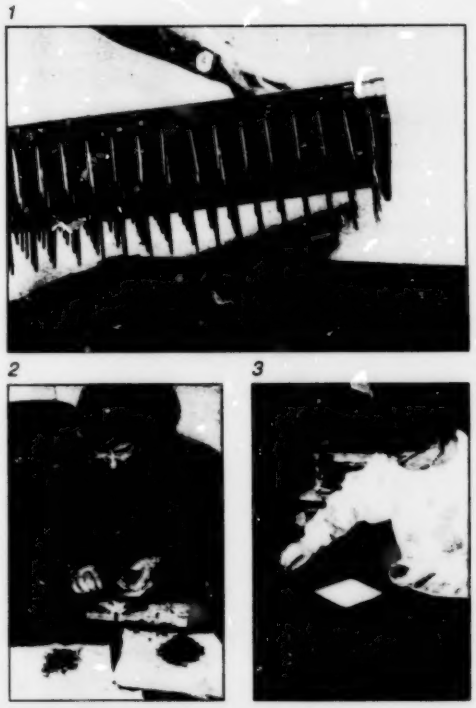
2.3.2 Rooting and growing cuttings

Cutting material is collected in late fall before the first major frost or after considerable accumulation of chilling. Cutting length varies by maturation, with 8- to 10-cm cuttings taken from the older soil-based hedges (Stage II) and 6- to 8-cm cuttings from Stage I donors. Cuttings are recut before being set and the foliage is stripped off the bottom 1-2 cm. The stems are then quick-dipped in Stimroot #3 which contains 0.8% I.B.A., and stuck in holes formed with a nail template in either styro 313's or Capilano containers. Soil mix contains peat and perlite at a 1:1 ratio by volume. Containers are then placed in a rooting environment and soil-drenched with a mix of 0.5 g/L of Benlate® (50% benomyl) and 2 g/L of Captan®.

The yellow-cedar rooting environment is similar to that for other conifer cutting programs. High humidity is maintained using an intermittent overhead misting system controlled by a mechanical leaf during rooting. During the first 2 months, misting is done from three to five times a day depending on the amount of sunshine. The misting duration usually lasts 10-15 seconds.

The cuttings are leached initially, and then throughout the season as needed to prevent salt build-up and to correct for differential drying.

Bottom heat, necessary for promoting callus and roots, is supplied by forced air run through polytubes, with perforated holes set under rolling benches. Benches are skirted with sheet plastic to minimize heat loss. The bottom heat temperature, set at 15-18 °C, is more important with cuttings of greater maturity. Cutting material from Stage I donors do not require as high a bottom heat temperature as cuttings from Stage II donors. Containers can be arranged in the greenhouse such that the more mature material is placed in "hot spots." Juvenile material, which is more tolerant of environmental fluctuations



Production technique for rooting yellow-cedar cuttings: 1) nail template used for forming holes in the growing media for ease of setting cuttings; 2) cuttings stripped and cut to length; 3) application of rooting hormone and setting cuttings.

during the rooting phase, can be placed along the outside edges of the benches where bottom heat and misting are more erratic. Air temperature is set at 4 °C to minimize shoot growth and to prevent freezing of the stock and misting system.

The cuttings are not fertilized until roots are observed on approximately 50% of the crop. As mentioned earlier, this is more important with Stage II donors. Table 2 outlines the fertilization regime used for rooting cuttings. Once the cuttings have rooted, growing, hardening, lifting and cold storage of the crop is the same as for seedlings.

TABLE 2. Growing media, fungicide treatment, and fertilization regime for rooting cuttings

Event	Details
1. media	1:1 peat:perlite by volume
2. fungicide	-drench cuttings after setting with mix of 0.5 g/L Benlate® and 2 g/L Captan®
	-repeat during growing season as needed to control botrytis
3. fertilizer	-no fertilizer until 50% of crop has roots
	-high soluble 20-20-20 @ 0.25g/L plus Stem® @ 0.5% by weight of fertilizer once every 2 weeks
	-increase soluble fertilizer to 0.5 g/L when 80% of crop has roots: turn off overhead misting and bottom heat
	-apply ferrous sulphate @ 0.25 g/L as needed and copper sulphate @ 0.05 g/L 2-3 times
	-reduce nitrogen as crop approaches target specifications

3 SEEDLING:STECKLING COMPARISONS

The field performance of stecklings compared to that of seedlings is the most important test. Do stecklings grow at similar rates to seedlings, and exhibit similar form? Do they respond to environmental stress in the same way? Do stecklings originating from different maturation levels respond differently? Finally, are there any advantages or disadvantages — in terms of growth, morphology, and tolerance to environmental stresses — to using stecklings over seedlings, and to using stecklings that originate from different maturation levels?

Comparisons between seedlings, and between stecklings originating from different maturation levels, have been made in the nursery, during field establishment, and in field trials. The results are summarized below:

1. **One-year-old stecklings originating from hedged cutting donors as old as 13 years from seed are similar to 1-year-old seedlings in height growth, shoot form, and root growth capacity. Stecklings have greater root collar diameter and root dry weight (Figure 8).**
2. **Stecklings originating from up to 11-year-old hedged donors compared to seedlings have similar height growth, survival, diameter, and shoot form in field performance trials (Figure 9).**
3. **One-year-old seedlings and stecklings exhibit similar water movement capability (Figure 10).**
4. **One-year-old seedlings and stecklings respond similarly to artificial drought stress and recovery, in photosynthetic capability, transpiration, stomatal conductance, and root growth capacity (Figure 11).**
5. **Root growth in newly planted seedlings and stecklings are similar (Figure 12).**
6. **Stecklings originating from mature donors have greater resistance to deer browsing and greater cold tolerance than seedlings and stecklings originating from juvenile donors.**
7. **There is substantial genetic variability among clones of yellow-cedar in height growth, form, and leader dominance.**

1) 11-year-old seedling; 2) 11-year-old steckling that originated from a hedged 7-year-old tree.

In a trial comparing seedlings and stecklings from 1-, 3-, and 7-year-old donors (Karlsson and Russell 1990), stecklings from 7-year-old hedges compared favourably to stecklings from 3-year-old donors and seedlings, in survival, form, total height, and diameter at breast height after 11 years in the field. Stecklings from 1-year-old donors significantly outperformed the other three propagule types for height and diameter, although these stecklings originated from cuttings that were from selected, vigorous terminal shoots. In this trial, deer preferentially browsed seedlings and stecklings from younger cutting donors.

In another field trial comparing seedlings and stecklings of 2-year-old donors from the same open-pollinated families (Karlsson and Russell 1990), there were no differences between the two propagule types after 9 years in the field for survival, form, height, and diameter.

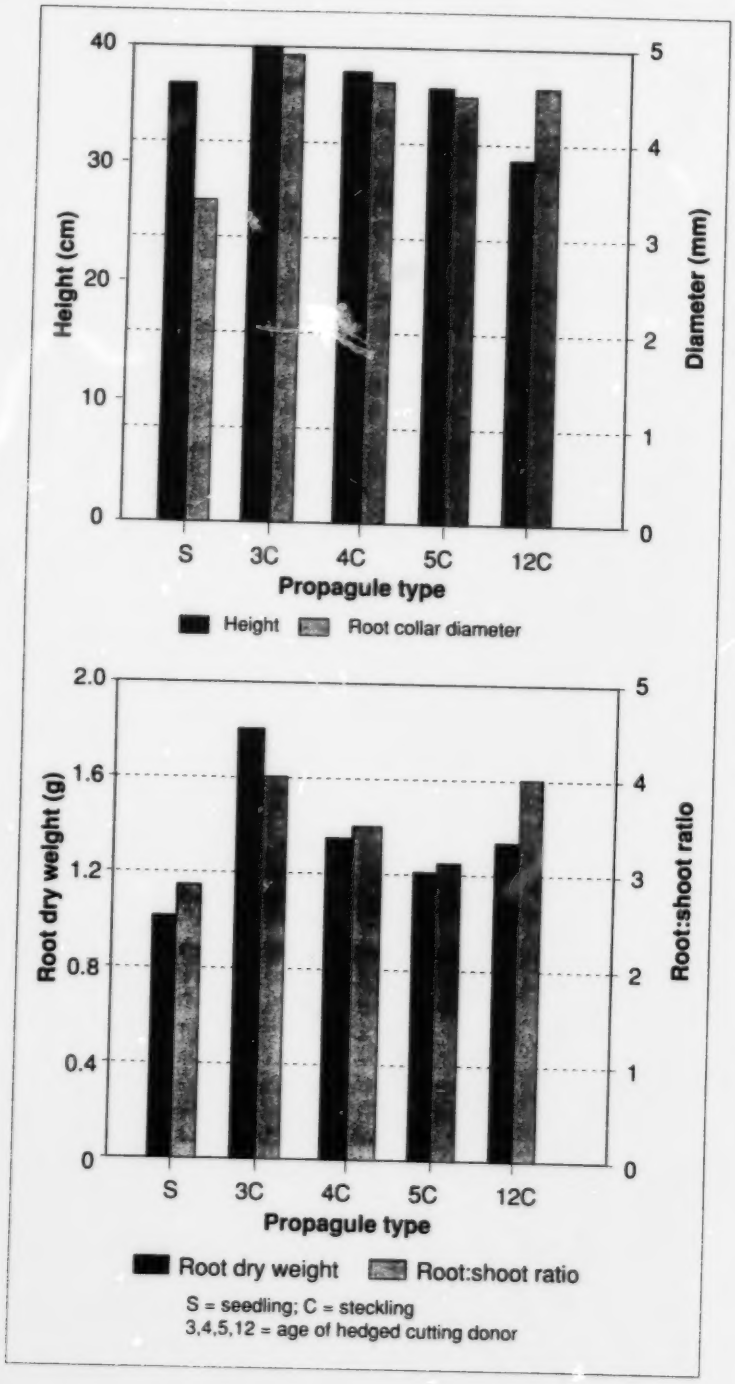


FIGURE 8. The effect of hedged cutting donor age (seedling-origin) on the performance of 1-year-old stecklings, and in comparison to that of 1-year-old seedlings: 1) height and root collar diameter; 2) root dry weight and root:shoot dry weight ratio.

The stecklings from all hedged donors of different ages compared favourably to seedlings. (Note in particular the performance of the stecklings from 12-year-old hedges.) All seedlings and stecklings were from the same seedlot, and were grown in the same environment and container type.

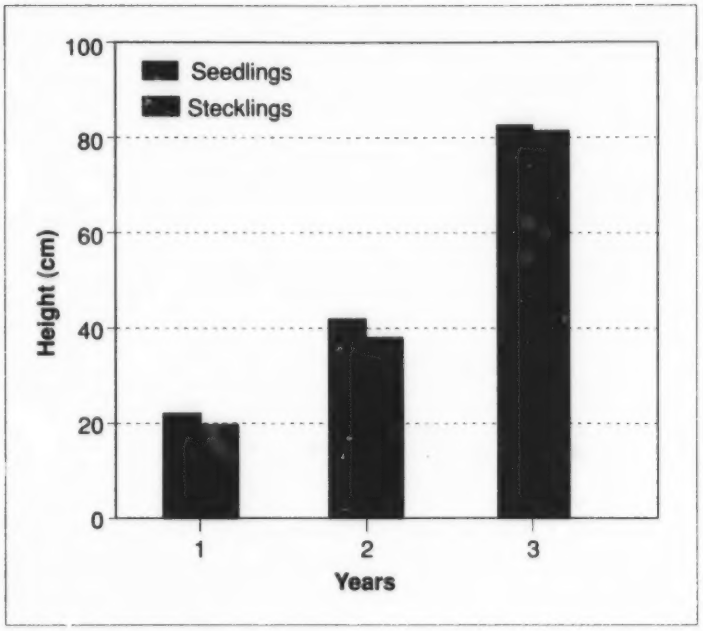


FIGURE 9. Early field performance of seedlings and stecklings originating from 11-year-old hedged seedling donors.

In a field trial comparing seedlings and stecklings from 25 cm hedged 11-year donors, there were minimal differences in height growth after 3 years.

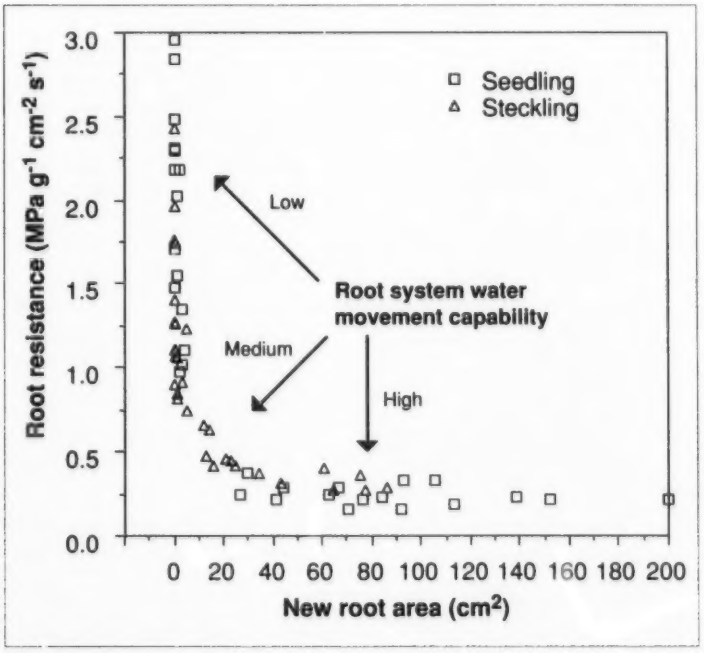


FIGURE 10. Comparison of seedling and steckling water movement capability.

How the root form of a steckling, compared to that of a seedling, affects plant water movement and subsequent field establishment is not known. The ability of a newly planted seedling or steckling to avoid severe water stress is critical to its survival and growth.

Water movement capability was found to be similar between seedlings and stecklings. In both propagule types, as new roots developed in the spring, water movement capability increased. Only a small amount of new root surface area (i.e., 20 cm²) is required in both seedlings and stecklings to reduce the initial overriding influence of root resistance on plant water movement. Water stress in newly planted seedlings and stecklings can be overcome by rapid new root development. This study found that both seedlings and stecklings perform equally well in reducing this reforestation site establishment problem.

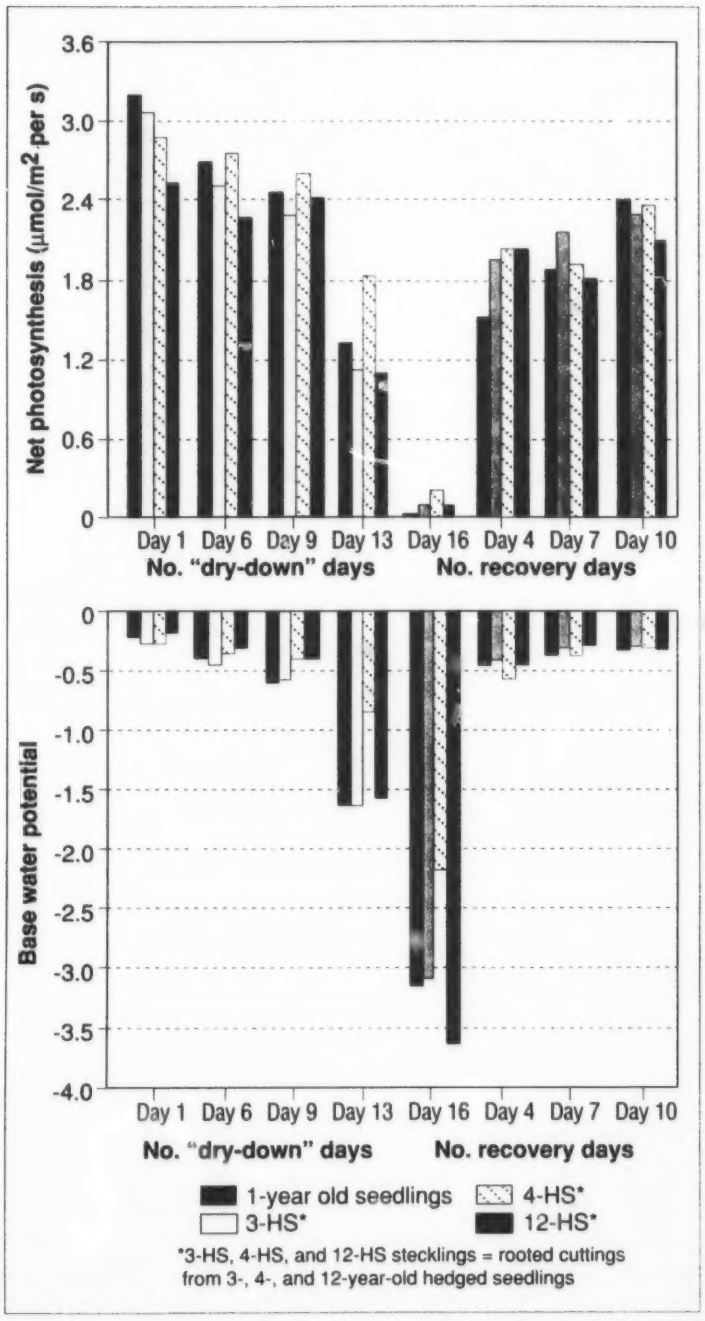
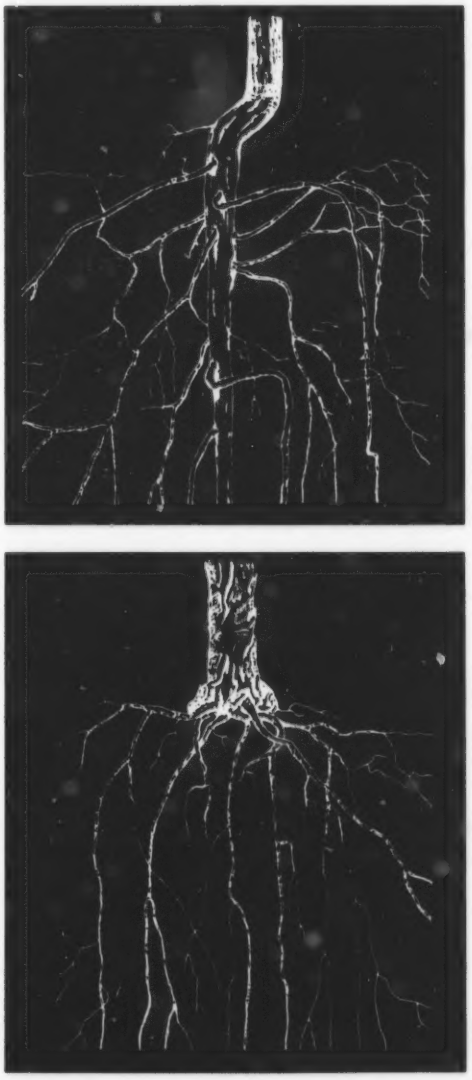


FIGURE 11. Physiological response of 1-year-old seedlings and stecklings originating from hedged cutting donors of different age.

In a controlled environment study, 1-year-old seedlings and stecklings originating from hedged cutting donors of different age were subjected to a 16-day drought, and then returned to a normal watering regime. All of the propagules responded similarly to water stress in their photosynthesis, transpiration, stomatal conductance (not shown), and root growth capacity (not shown).



1-year-old seedling (top) and steckling root morphology.

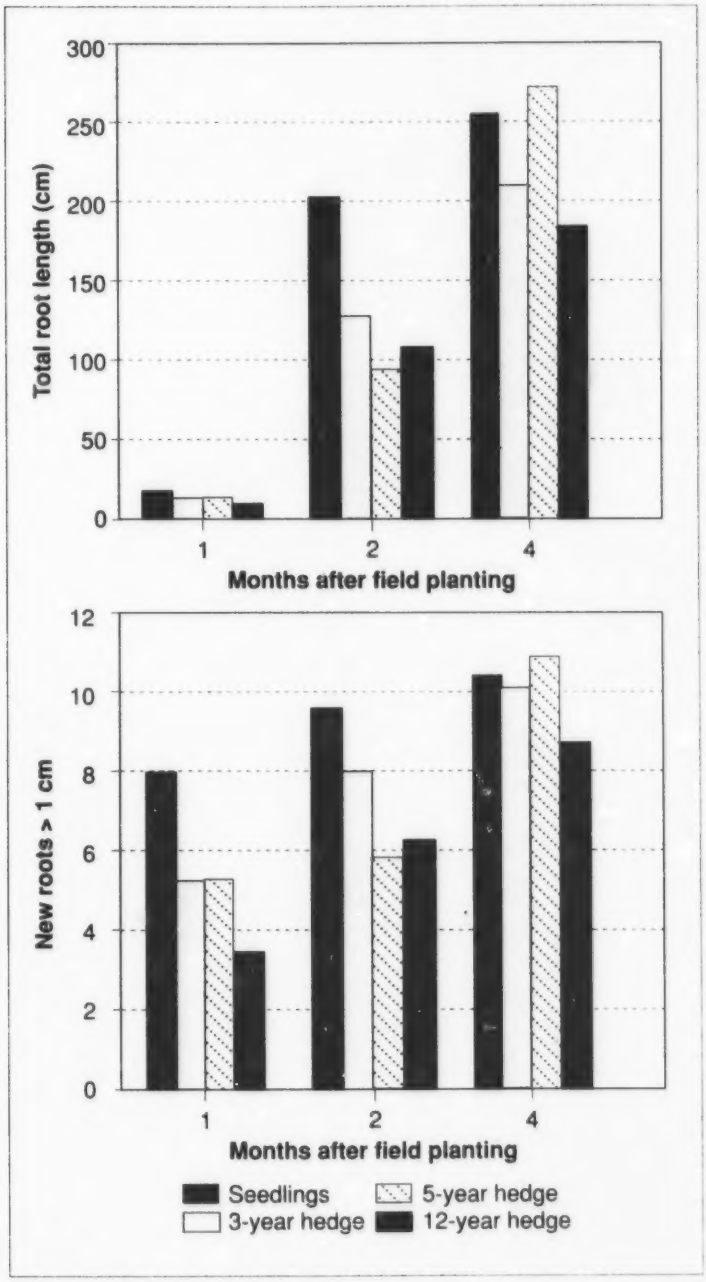


FIGURE 12. Root growth response of seedlings and stecklings from hedged cutting donors of different age during field establishment: 1) total root length; 2) and new roots.

Both seedlings and stecklings require sufficient root growth after field planting to successfully establish on a reforestation site. Under optimal environment test conditions, both seedlings and stecklings from hedged cutting donors of different age were able to produce a large number of roots under standard root growth capacity testing. However, root growth for these propagule types under field conditions was low during the first month after planting. Root growth increased during the second through fourth month after planting in all stocktypes tested. Newly planted yellow-cedar develop only a few new roots, but these grow to very extended lengths. Past research has shown that root growth at these levels is sufficient for good survival of field-planted coastal conifer seedlings. Thus, both seedlings and stecklings are capable of producing sufficient roots for successful field establishment.

4 SUMMARY

For over 15 years, yellow-cedar stecklings have been grown in British Columbia. Currently, over one-half million stecklings are planted annually on reforestation sites with encouraging results. The oldest yellow-cedar steckling research plot is now 13 years old and, to date, survival, growth, and form are similar to seedlings planted in adjacent plots. Thus, we are gaining knowledge and confidence in the use of stecklings for reforestation.

An efficient and economical nursery production system for producing yellow-cedar stecklings exists, and has successfully been transferred to commercial nurseries. The knowledge and techniques are now available for controlling and manipulating cutting maturity and physiology. Research has successfully linked maturation with physiological responses, giving us a better understanding of the processes necessary to produce good quality stecklings.

Yellow-cedar cutting donors are now being produced on a 5-year cycle. Seedlings are grown in 5-L containers in greenhouses and holding areas for 5 years, and are intensely managed. This includes regular pruning, to produce large numbers of good quality cuttings. Cuttings from these Stage I donors will give consistently good results with minimal nursery cultural manipulation.

If gains are to be made from the selection of genetically improved clones, however, both growers and foresters must be prepared to grow stecklings originating from Stage II donors. Research results have repeatedly shown that using cuttings from Stage II donors will result in over 70% shippable stecklings, and that survival, growth, and form in the field are similar to that in seedlings. As well, Stage II stecklings are potentially more frost-tolerant and resistant to deer browsing.

Stage II cuttings do require more attention at the nursery stage and will produce fewer shippable stecklings than Stage I cuttings. The increased cost per propagule can be justified by the planting of genetically improved clones. Results from a yellow-cedar clonal trial indicate that a 15% gain in height, and a concurrent improvement in stem form, at 4 years, is possible through clonal selection. This gain, however, is only possible through the continued manipulation of cutting donors to delay maturation, and the production of quality cutting material.

Yellow-cedar clonal field trial.

As more information becomes available on steckling performance from older hedges, more confidence is being gained for using them in clonal forestry. Clonal forestry is the testing, selection, and deployment of genetically improved clones for reforestation. Clones, which are multiple rooted cuttings from a single individual, are tested against each other in replicated field trials for a number of years. Following selection of the best clones based on height, diameter, and form, the clones must be repropagated. Their performance is then checked to see if they did as well as they did when they were first propagated.

Clonal forestry conjures up images of vast areas of land planted to a single, uniform clone. This is not, however, a viable strategy. Trees are long-lived, sessile organisms, and must withstand many different environmental stresses during their lifespan. Thus, to avoid a scenario in which a single clone is wiped out by a pest after 40 years of growth, only clonal mixtures involving many clones (>100) should be used.

5 REFERENCES

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